

# QUESTIONS AND SOME ANSWERS: Envirotemp® FR3® Dielectric Fluid (FR3 Fluid)

**What maximum top oil temperature rise, average winding temperature rise and hottest spot winding temperature rise are you expecting for the transformer containing FR3 fluid? What are the temperature rises for the other transformer manufacturers' offers being compared?**

Waukesha is offering a design with FR3 fluid that limits the temperature rise to 65°C, the same as you have specified for mineral oil. We are also offering a transformer designed for mineral oil but filled with FR3 fluid. The transformer will run hotter with FR3 than with mineral oil and may likely exceed the 65°C temperature rise limit. However, according to laboratory data by Cooper Power Systems, the cellulose insulation will age more slowly in FR3 fluid than in mineral oil so the insulation will likely last longer in the operating in FR3 fluid than it would if operating in mineral oil.

**Are the FR3 fluid designs you are evaluating designed for 65°C rise with mineral oil or 65°C rise with FR3 fluid?**

Waukesha offers both. Because of the higher viscosity of natural ester fluids, more cooling needs to be added to achieve a 65°C rise with FR3 fluid. This cooling could be in the form of more cooling fans, more radiators or larger cooling ducts in the windings. Our sophisticated temperature calculating computer programs look at all 3 of these cooling options to give an optimized design.

Waukesha has retrofilled many transformers with FR3 fluid and does not recommend derating the transformers. We have also shipped new transformers from our factory that were designed with mineral oil and field filled them with FR3 fluid, without derating or changing the warranty. These mineral oil designs will operate at somewhat higher temperatures than they would if filled with mineral oil. However, the cellulose aging rate is much slower with natural ester fluids and so the insulation should last longer in the FR3 fluid at a higher temperature than it would if in mineral oil at the lower temperature.

Waukesha gives you the option of temperature rise.

**Does the supplier of the transformers being evaluated have a temperature rise program capable of accurately calculating the temperature of a transformer using a fluid other than mineral oil?**

Waukesha has a program that starts with the fundamentals of thermodynamics and heat transfer wherein we can change the characteristics of the fluid. It was / is common in our industry to have a large database of heatrun test results against which are run multiple linear regression analysis to develop empirical formula for calculating temperature rise of new designs. This is a reasonable approach as long as the new design is similar to the ones in the database. If something is changed, like the characteristics of this dielectric coolant, then this method doesn't work.

Raj Ahuja and Bob Del Vecchio of Waukesha Electric authored a paper presented at the CIGRE meeting in 2007 titled "Comparison of the Thermal Performance of FR3, a Natural Ester Based Coolant, with Transformer Oil". This paper describes in more detail, the factors taken into account in temperature calculations in transformers. A copy is available upon request.

**Has the supplier done temperature rise tests with FR3 fluid to verify the accuracy of their thermal calculation program?**

Waukesha has done this. The results so far are shown in the paper referenced in the previous question #3.

**Does the use of FR3 fluid change the transformer warranty?**

Waukesha Electric offers the same Five or One Year Warranty regardless if filled with mineral oil or FR3 fluid. Waukesha does require that we do the assembly and fluid filling in order to get this warranty. The rationale is that this is a new fluid and we have spent a significant amount of time on handling procedures and crew training. We don't want our customers to be disappointed with a potential mishap.



## How many transformers has each supplier filled with FR3 fluid?

By the end of 2008, Waukesha will have built 26 new transformers filled with FR3 fluid and retrofilled 29 transformers with FR3 fluid. The retrofills were of several different manufacturers and all different ages.

## How do you minimize the residual mineral oil content in the FR3 fluid?

Waukesha has written internal procedures on filling units with FR3 fluid. These procedures were drafted specifically to reduce residual mineral oil content and also to minimize / eliminate any cross contamination of FR3 into the mineral oil system and also any mineral oil into the FR3 system. The residual mineral oil content is controlled by a combination of drip time, fluid removal, flushing and filter changes. Following Waukesha's internal procedures, we estimate the residual mineral oil content in new or retrofilled transformers to be typically less than 2%. As long as there is less than 7.5% residual mineral oil content in the FR3 fluid, the 360°C fire point of the FR3 will be preserved.

Although the fire point of FR3 fluid remains unchanged with residual mineral oil content of up to 7.5%, the flash point does change. Determining the flash point of a sample of fluid taken after filling with FR3 can be used to determine the residual mineral oil content. Refer to Cooper Power Systems document (located on the Waukesha Electric website-see question 14 below) "Envirotemp FR3 Fluid Testing Guide" Section R900-20-12, Reference Document, July 2004, page 6, Figure 3 titled "Flash and fire points versus mineral oil content." Knowing the flash point of the sample and using this graph will lead to a good estimate of residual mineral oil content.

## Can Dissolved Gas Analysis be used with natural ester fluids?

Yes. This very useful diagnostic tool for assessing the condition of mineral oil filled transformers is also a useful tool for natural ester dielectric fluid filled transformers. The key gas analysis as described in ANSI C57.104 is still valid for use with natural ester dielectric fluid filled transformers. For example a DGA showing acetylene is still indicative of a high-energy discharge and likely to be a problem that should be investigated further. There are different gas ratios used to help distinguish among different possible causes of gas generation. Unfortunately, these ratios are not calibrated for natural ester dielectric fluid filled transformers and should not be used.

EPRI has a project wherein they got funding from several utilities to conduct tests to find the gas generation rates of the various gasses so that the gas ratio methods of analysis could be recalibrated for natural ester fluids. Upon completion of these tests, it is EPRI's intention to supply this information, free of charge, to the IEEE Transformers Committee for use in developing a natural ester fluid gas guide. Both Waukesha and Cooper are involved in the EPRI project by participating in monthly conferences and by providing expert advice. Cooper has recently started recommending the Duval Triangle can be used to interpret the DGA results in FR3 fluid.

## What about cold starts of transformers filled with FR3 fluid?

According to data from NOAA, almost nowhere in the lower 48 states gets cold enough for long enough for this to be an issue. There is a presentation available upon request that gives all the details of this. Also, EPRI has an ongoing project wherein they will have testing conducted to better understand this issue. Upon completion of these tests, it is EPRI's intention to supply this information, free of charge, to the IEEE Transformers Committee for use in developing cold start guidance.

To date, there have not been any reported issues related to cold starts of distribution or power class transformers that Waukesha is aware of. Both Waukesha and Cooper are conducting research in this area to further understand if there are any issues related to cold start.

## Can natural ester fluids be used in load tap changers?

Not yet. Waukesha Electric has two concerns with natural ester fluids in free breathing LTCs. The first is polymerization of the fluid from exposure to oxygen. This can be overcome by installing a Waukesha Nitrogen generator that produces N<sub>2</sub> on site and bleeds a small amount continuously across the gas space in the LTC. This removes the arcing gases produced and also excludes oxygen from the fluid. The second concern is the physical movement of the contacts through a more viscous fluid and it's effects of timing. Waukesha has conducted timing tests using mineral oil, natural ester fluid and synthetic ester fluid (Envirotemp 200 by Cooper Power Systems). These tests confirmed previous test results showing acceptable timing in mineral oil down to -40°C. Tests in FR3 fluid were good down to about -15°C at which temperature the FR3 fluid started to gel but it took quite a while (2 days in -70°C ambient with pump running). Our solution is to put a PTC (Positive Temperature Coefficient heater) in series with our oil filtration system and turn this on when the temperature gets to -10°C so that the fluid never starts to gel. Cold temperature testing of this system is scheduled for

second quarter of this year. It is likely these solutions will be retrofitable on Waukesha® UZD™ Load Tap Changers later this year. Reinhausen has issued a statement that they should be contacted for any fluid application other than mineral and would advise on a one-on-one basis.

### Is oil containment still required with FR3 fluid?

Probably yes. There are so many bodies that might have jurisdiction in this matter it is not easy to give a universal answer. There are locations where you wouldn't want several thousand gallons of water running around so some form of containment is likely. However, that being said, it is also possible that if there is a spill, that the remediation activities and associated costs might be much less than with mineral oil or any other less biodegradable fluid.

### Are any of the typical test values going to be different with a transformer filled with FR3 fluid?

Yes. The insulation dissipation factor (power factor) will likely be higher by as much as 50% or more but this will depend on how much time has elapsed after filling with FR3 fluid. Assuming the paper insulation had mineral oil in it to start, and then filled with FR3 fluid, it will take some thermocycling to heat the mineral oil in the paper which expands into the FR3 fluid and then FR3 fluid is pulled into the cellulose when it cools. This thermocycling will eventually equalize the uniformity of the fluids.

Also the winding resistance to ground will be lower by as much as an order of magnitude.

Neither of these differences is either good or bad, they are just different than mineral oil. It is just the nature of a different material. Available upon request is an IEEE paper written and presented by Steve Moore at the 2005 IEEE show in Dallas, TX, titled "Some Considerations for New and Retrofill Applications of Natural Ester Dielectric Fluids in Medium and Large Power Transformers".

### How does the carbon footprint of natural ester fluid compare to mineral oil?

The carbon footprint of natural ester fluid is MUCH LESS than that of mineral oil. In fact, according to calculations made by NIST (National Institute of Standards and Technology) using their BEES (Building for Environmental and Economic Sustainability) calculator, natural esters have less than 2% of the carbon footprint that mineral oil has. This can be an easy step for utilities trying to find ways to reduce their carbon footprint.

### Where can I find more information on FR3 fluids?

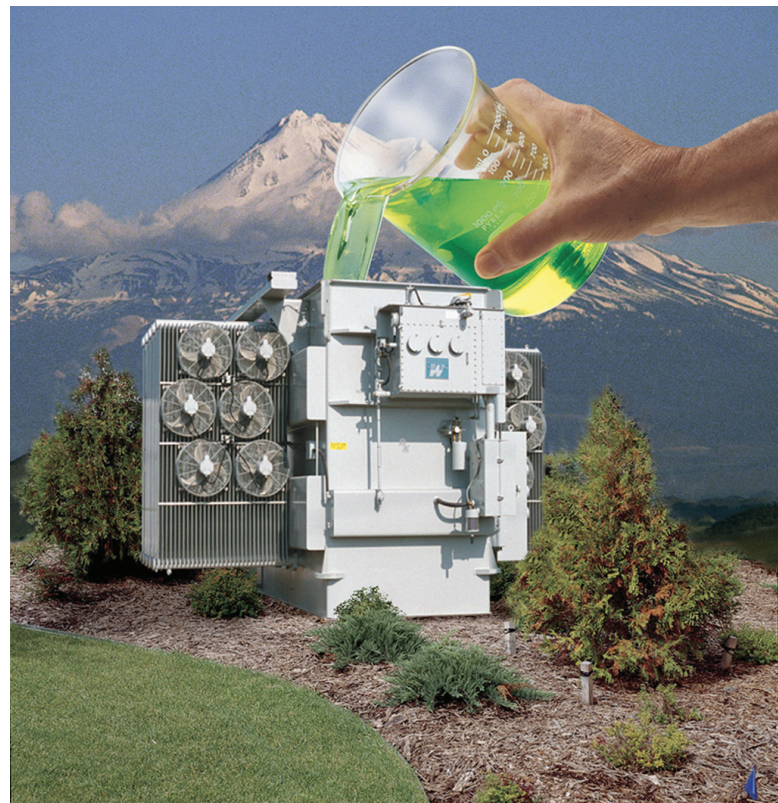
On the Waukesha Electric Systems website. Go to [www.waukeshaelectric.com](http://www.waukeshaelectric.com). Roll your cursor over the top tool bar to "TOOL/RESOURCES" and a drop down menu will appear. Click on the top item "Waukesha Library." Then scroll down to the 4th colored bar for Envirotemp "FR3 Natural Ester Fluid." There are 23 documents here with significant information for a basic understanding of natural ester fluids.

### How does the price of FR3 fluid compare to mineral oil?

Presently FR3 fluid is a few dollars more per gallon than mineral oil for the initial purchase price. There are significant benefits to natural ester fluids that make it attractive even at a higher price. As the price of mineral oil and commodity seed oil (soybean oil) continue to fluctuate (go up), this difference in price may vary over the coming years.

### Will all my transformer suppliers offer a transformer filled with natural ester fluid?

That depends on who you allow to bid on your transformer requirements. There are 3 suppliers in the United States that offer transformers filled with FR3 when requested. There is another supplier that apparently only offers FR3 in transformers rated 15 MVA ONAN or below. There are some other suppliers that may or may not offer it. Please refer to questions 1 –6 above in order make a fair comparison of various natural ester fluid filled transformer offers.



## How much research and development has Waukesha Electric Systems done with FR3 fluid?

Quite a lot actually. Several years ago we started with basic material compatibility testing. Many materials used in distribution transformers are also used in power transformers and these materials were tested for compatibility. There are some materials that are used in power transformers that are not used in distribution transformers and these additional materials were tested by Waukesha to ensure compatibility. All were found to be OK. Also Waukesha performed power frequency, impulse and partial discharge testing with FR3. In 2007, Waukesha tested its UZD™ Load Tap Changer's performance in FR3 fluid. Additional testing is planned for 2008 including cold temperature investigations.

## Does FR3 fluid contain corrosive sulfur?

Not that can be determined. Cooper has tested their FR3 fluid at higher temperatures and for longer times than are specified in ASTM D1275-06 Method B test for corrosive sulfur and none could be detected.

## SUGGESTIONS FOR SPECIFICATION WORDING

- The transformer shall be designed for 65°C temperature rise with FR3 fluid. The manufacturer shall demonstrate the capability of his thermal calculation program to estimate temperature rise with FR3 fluid and if acceptable, will provide calculated temperature rises with FR3 fluid.
- The transformer shall be designed for 65°C temperature rise with FR3 fluid. Transformer shall have heat run test performed with FR3 fluid.
- The transformer shall be designed for 65°C temperature rise with mineral oil but filled with FR3 fluid. The manufacturer shall demonstrate the capability of his thermal calculation program to estimate temperature rise with FR3 fluid and if acceptable, will provide calculated temperature rises with FR3 fluid.
- The transformer shall be designed for 65°C temperature rise with mineral oil but filled with FR3 fluid. Transformer shall have heat run test performed with FR3 fluid.
- For transformers containing natural ester fluids, the oil preservation system shall be a positive pressure nitrogen system so that oxygen is excluded from the gas space in the transformer OR
- For transformers containing natural ester fluids, the oil preservation system shall be a positive pressure nitrogen generator system so that oxygen is excluded from the gas space in the transformer OR
- For transformers containing natural ester fluids, the oil preservation system shall be a conservator system with a bladder so that oxygen is excluded from contact with the FR3 fluid.

NOTE: All mention above of "65°C temperature rise" means 65°C top oil and average winding temperature rise and 80°C hottest spot winding temperature rise.



**A N S P X B R A N D**

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